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SPECIAL REPORT NUMBER LM 9.

LAKE CURRENTS AT A SINGLE STATION

PUBLIC HEALTH SERVICE
CHICAGO, ILLINOIS

APRIL 1963

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Three types of automatic recording current meters were evaluated in the study of currents in Lake Michigan. The Woods Hole meter was selected because of the established performance record of its internal components, type of data collected and lower costs. The test data were examined to determine the reliability and sensitivity of meters for measuring both speed and direction. The median values for speed and direction were examined for random fluctuations and the 95 per cent confidence limits indicate the instruments had a sufficient degree of precision. The data tabulated for May to July 1962, show that under certain conditions an effluent could move, at low speed with relatively little mixing, for over four days.

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Great Lakes-Illinois River Basins Project

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INTRODUCTION

Many of the theoretical concepts of water movements in the oceans or the Great Lakes have defied testing because of the lack of adequate instrumentation. With the advent of the Savonius rotor and the development of the Woods Hole meter less than three years ago, a new tool was made available to the scientist. An important feature of this meter, the automatic readout of recorded data, was perfected in July 1962. This automatic recording current meter with the ability to record up to six months unattended, is the basis of this study.

Description of Study

The study of currents in Lake Michigan by using current meters began October 21, 1961 with the setting of an experimental telemetry station. The station was first set about 25 miles northeast of Chicago, see Figure 1, but was removed after three days because of a defect. It was reset on May 15, 1962 about fifteen miles northeast of Chicago (Figure 1). From May 15 through November 1, 1962, several different types of stations were set for the purpose of evaluating meter performance, mooring systems, and other features of the instrumentation, preliminary to the full scale study.

Purpose

This report will describe the results of the observations with respect to the following factors:

1. The reliability and sensitivity of instruments under field conditions.

2. The operating characteristics of different types of current meter installations.

3. The relationship of water velocity with time and with depth, for use in programming full-scale operations with all stations in the lake.

4. To secure early information concerning the existence, or absence of prevailing currents in the vicinity of Chicago.

5. The relationships between winds-on-shore and lake currents.

Previous Studies

Other important factors pertinent to this study were also explored including: a literature search on past studies; where (geographically) to locate meter stations; the amount of time required; the amount and kind of data to be collected; and a review of the logistics of conducting the study.

A detailed literature search disclosed three important studies pertinent to the measurement of currents in Lake Michigan. In the years from 1892 through 1894, Mark Harrington of the U.S. Weather Bureau released over 1500 drift bottles in the lake, of which only about 203 were recovered during the three-year period (1). These returns formed the basis of the first map of Lake Michigan surface currents. In 1954-55, James Johnson of the U.S. Bureau of Fisheries completed an intensive study of surface currents using drift bottles and drift envelopes (2). Out of 6260 releases, some 2870 were recovered during this study. The results indicated that during 1954 no stable pattern of surface currents existed. In general, Johnson found the drift was from west to east and the north-south movements were about equal. A similar pattern existed in 1955 except that the drift in the eastern areas was mainly to the north. In 1958, Ayers and others published the results of a series of synoptic surveys (3), in which they applied a modification of the dynamic height method and published the first map of Lake Michigan showing subsurface water movement. The method used, however, is open to question, because of the choice of boundary conditions.

Townsend (4) took sharp issue with Harrington on the method of presentation of data. He stated that in such a confined area as Lake Michigan Harrington could not assume curved line motion but should have used straight line motion. Townsend's ideas were partially verified by studies on Lake Erie (5).

It is difficult to translate drift card or bottle movements over many days into those of actual currents. The only positive statement that can be made about drift methods is in reference to the points of release and retrieval. Such movements at best can only demonstrate a type of pattern between the times of release and recovery. The seemingly random changes between Ayers' and Johnson's work graphically illustrate this point. The more recent studies using bottles and cards did not claim to show anything other than the conditions that existed at that time and place. Harrington, however, tried to pin down specific current patterns from far less data over a much greater time span. However, the meters which exist today were unknown five years ago and earlier scientists used the tools then available.

The dynamic height method of obtaining subsurface current data has not been substantiated by means of current meters. Criticism of the method is based on two assumptions. One, the method assumes a zero velocity depth level which may or may not be correct; two, the theory assumes constancy in the isothermal lines over a short period of time, whereas it is known that internal waves may produce very striking thermal changes in lakes and also in the ocean (6).

Since none of the past studies shows net circulation, maximum current speeds, effects of storms, or detailed inshore circulation, further work is necessary to give the answers needed today.

STUDY PROCEDURES

Of the various methods for the investigation of currents, a number of fixed stations with automatic recording meters was selected as most applicable to the Public Health Service comprehensive study of lake water quality.

Three types of measuring systems were considered seriously by the U.S. Public Health Service: The Woods Hole Oceanographic Institution meter (7) developed by Dr. William S. Richardson (Figure 2); a telemetry system devised by the U.S. Corps of Engineers (8) for the Public Health Service (Figure 3); and a modular system (9) devised by Marine Advisers, Inc. (Figure 4). The first is self-recording and has a mechanical recording system. The other two are also self-recording but have electronic recording systems. All have many desirable features not found in other types of current meters, such as:

1. The ability to measure low current speeds, down to about 0.03 feet per second (fps) by utilizing a Savonius rotor (8).

2. The ability to operate untended for up to four months while recording observations hourly.

3. The ability to measure direction to $\pm$ 7°.

4. The ability to record observations at shorter intervals than one hour.

The meters have individual characteristics which make them desirable for use in different locations. After the trial period, the Woods Hole meter was selected as the most suitable of the three systems tested.

After the method of study was selected and testing of meters was underway, plans were devised for station locations, number of stations required and data processing. The selection of stations and the number of meters per station were subjects of a conference held in Chicago with scientists from the Great Lakes States and Canada. It was decided that the standard procedure of equal area and depth coverage was the most logical method. In order to study all of Lake Michigan it was agreed that between 40 and 60 stations should be set. The number of meters to be set posed a problem because of the variability of the thermocline. It was readily established that the meters should be set at fixed depths, and at

closer spacing in the upper layers. The depths selected were: 30, 50, 75, 100 feet and each succeeding 100-foot level. No meter was set less than 30 feet below the surface because of problems resulting from surface waves.

The preliminary recording of data was different for the various types of stations. The telemetering station recorded hourly on its internal recording system and transmitted other data every four hours by radio to a receiving station. The Woods Hole meter at different times was used on a continuous recording mode and then on a mode recording 50 seconds continuously once every twenty minutes. The telemetry system reports total revolutions of the Savonius rotor in each four-hour interval together with one instantaneous direction reading made at the time of reporting. The Woods Hole meter records continuous speed and direction values throughout each fifty second period on a photographic film within the instrument. The recording for the full-scale study is set at a continuous fifty-second recording period once each thirty minutes for the winter months, but intervals will be reduced to twenty minutes for the rest of the year. The longer period was adopted for winter operation to provide a margin of safety against exhaustion of the power supply batteries inside each unit. During severe winter weather it will be impractical to visit the stations for retrieving data, replacing batteries, and other servicing.

RESULTS OF STUDY

The results are shown on a series of graphs (Figures 7 to 15). These graphs present results of statistical tests on the data obtained from the current meters. Speed readings are given in feet per second. Direction readings are given in terms of degrees clockwise from magnetic north. The readings for direction given in this report represent the direction from which the current is coming.

Figures 10 and 11 were examined for correlation and equality in direction. If the absolute value of the median difference of the readings between two meters is significantly less than 90° a positive correlation exists.

Reliability

The reliability and sensitivity of the meters was determined by an examination of results, i.e., speed and direction data, rather than by an analysis of the physical characteristics of the meters. A study of the data alone will not disclose systematic errors in the measurements; however, such errors are believed to be small, based on tank tests in which the sensors are towed through still water (8).

The data used for reliability evaluation were from two separate stations - the telemetry station with three meters, set at 60, 90, and 120 feet, and a station with one meter of the Woods Hole type set at 120 feet. The two stations were within 300 feet of each other. The recording interval for the telemetry station was once every four hours with some observations at ten minute intervals. The total time of recording was 63 days. The Woods Hole meter recorded continuously and the data were printed out at 1.25-minute intervals. The record length for this meter was 6 days, July 5 to 10, 1962.

Figure 5 shows a series of current meter readings taken during a period of increasing flow. The data show two types of changes in the speed, a long-period systematic rise and a short-term random fluctuation. The long-period rise shows an increasing current speed. The short-term random fluctuation could be due to changes in the current speed or to instrumental error. At this time it is not possible to distinguish between the two changes and they are grouped together and treated as physical measurement limitations. The amount of the random fluctuations is used to estimate the precision (repeatability or consistency) of the data.

The problem of variation measurement is to measure the short-term changes without including the long-term systematic variation. The simplest solution to this problem is to assume that the long-term systematic variation is approximately zero over a short period of time (Figure 5). Thus, over a short period of time, the total variation can be used to approximate the random fluctuation.

Under steady-state conditions, the larger the quantity of data collected, the more accurately it will represent the population of which it is a sample. However, the larger the quantity of data used, the greater the time span. Thus, the problem is to use a large quantity of data without spanning a long period of time. The solution is to have as short a period of time between observations as possible.

The data in Figure 5 from the Woods Hole meter were plotted from the readings made at five minute intervals. The figure is a plot of magnitude (or speed) against time. The plot represents a portion of a 40-hour period and indicates that the meter is capable of detecting long-term systematic changes in speed. However, initial tests showed a large random variation in direction at higher speeds, due to the type of mooring system used.

The original mooring system used by Dr. Richardson of Woods Hole in the Atlantic Ocean was modified for use in Lake Michigan. The Atlantic installation used a synthetic line anchored to the bottom and held at the surface by a large float. Ice and severe winter conditions prevented the use of a slack wire mooring system in Lake Michigan. The Project used a taut wire system with a subsurface float which has a positive buoyancy of 550 lbs. A surface float, for use in ice-free periods, was attached by a slack line to the subsurface float. An examination of the original test data showed unusual variations in the direction vane. Observation disclosed that during windy periods the large surface float was capable of jerking the lower taut line in any direction. To prevent this action and the consequent swinging of direction vanes on the meters, the mooring system was changed to a two-line system (Figure 6). This present system leaves the meter line almost completely free from external stress.

The mooring system used at the telemetry station did not have a large surface float relative to the subsurface float. Therefore, the pull of the surface float did not apparently affect the direction vane on the sensors. Thus, the data from the telemetry station were used in the analysis of direction reliability. The

ten-minute time intervals were used for the analysis. Figure 7 shows confidence limits using ten-minute intervals (10, p. 294). The results in Figure 7 show acceptable precision in both magnitude and direction at each of the levels (60', 90', and 120').

The Savonius rotor has been subjected to tests in an effort to determine its degree of reliability, response in turbulent motion and dependability over periods of time. The rotor, as presently used, is sensitive to about 0.03 fps as shown by tow tank tests conducted by the Corps of Engineers (8). Tests by Gaul indicate that the rotor is very reliable between 0.08 fps and 7.0 fps (11).

The rotor is omni-directional, which means that it will sense motion from any direction in a horizontal plane when set with its axis of rotation vertical. The orbital motion of waves produces a surge forward and then backward as it passes. This effect on a Savonius rotor would show as an increased speed. Wave action, during severe weather conditions, can be detected as deep as 50 feet. For this reason, the uppermost current meter is at the 30 foot level and will only be affected during the more adverse conditions. Figure 8 shows a typical rating curve for the rotor made by the Corps of Engineers.

The direction data could not be used for the Woods Hole meter because of the problems inherent in the old system of mooring; however, the data from the telemetry station showed precision in both magnitude and direction.

Flow Characteristics

A preliminary examination was made of the flow data. The following were investigated: relationship between wind and water, relationship between readings at different stations, relationship between readings at different levels, range of speeds, and possible predominant directions at different speeds.

It should be remembered that much of the report depends on statistical testing for relationships or correlations between two variables. A positive result (correlation) implies ninety five per cent confidence that a relationship or correlation does exist. A negative result (no correlation) implies one of the following two possibilities: either no relationship exists between the variables in question or a relationship does exist but the nature of the statistical test or the data was such that the relationship could not be detected.

Two limitations on the applicability of the findings in this report should be mentioned. It should be remembered that the current meter data represents samples from a changing physical system. Thus, physical relationships which may occur for one period of time may not necessarily occur for any other period of time. For example, there is a definite possibility of systematic, seasonal differences that are not reflected in the tests reported herein. Also, the relations which are here established represent average effects. The only thing necessary to produce a non-random effect during the whole period of time is a large enough non-random effect some of the time to affect the overall result. The conclusion that can be obtained from a positive result is that one can expect (with 95% confidence) that the result held more than fifty per cent of the time, for the period of study. (10, p. 280).

An attempt was made to correlate wind data and the current data. It should be noted that wind data was estimated (from shore based stations) for the 30 foot level (above the lake surface) and the current data was taken at 60 feet below the surface. Various relationships were tried, using a variety of ways of weighing past wind daily averages and correlating with present currents. No positive correlation could be found. This does not necessarily mean that wind does not affect water currents. There is every reason to assume that such a relationship exists, but detection may be difficult at the greater depths.

A test was made to correlate currents at different depths (60', 90', and 120') at the same station. Both magnitude and direction showed positive correlation at 95% confidence (10). Figure 9 shows the magnitude (speed) relationship at sixty and ninety feet. The positive correlation can easily be seen (10, p. 297). It can also be seen that the speeds at 60 feet are greater than speeds at 90 feet on the average (a difference in medians at 95% confidence is shown). Speeds at the 120 foot depth were generally lower than the minimum detectable speeds on the current meter. Figures 10 and 11 show a comparison of directions at different depths. The current at 90' was normally to the right of the current at 60'. The current at 120' appeared to the left of the current at 90' on the average. This fact was shown at 95% confidence. The theory of the Ekman Spiral, states in part, that currents tend to rotate cum sole, that is, clockwise in the northern hemisphere and decrease in speed with increasing depth (15). The clockwise rotation is due to rotation of the earth. It is an open question if the Ekman spiral theory applies to Lake Michigan because of its relatively shallow depth.

Figure 12 shows a histogram which is designed to show the range of speeds at different depths. The abscissa is a group of speed ranges and the ordinate is the per cent of time that the readings fall into the range specified in the abscissa. It can be readily seen that there are differences in speeds at different depths. The greater speeds are the bars which are farther to the right.

Figures 13, 14, and 15 show polar coordinate diagrams of speed and direction at the three depths observed. Table 1 shows the number and per cent of observations in each quadrant, the average angle and speed for each quadrant and the maximum number of times the current was found in a specific quadrant. The number of times the readings were in the northwest quadrant was unusually high, indicating a 95% probability non-random effect (12, p. 35). One meter showed northwest currents over four days in succession (Table 1).

Valuable information is presently obtainable from the few meters used. Two current meter stations placed in the same area showed correlation in direction, on the average. Some information is now available concerning variation of water speed with depth. As expected, relatively high speeds at one depth will on the average lead to relatively high speeds at another depth. Also, the speed of the currents showed a decrease with depth. The direction of currents correlated positively at different depths. Differences in direction at different depths were shown to be detectable. On the average the current at 90' was shown to be to the right of currents at 60'. The currents at 120' appeared to the left of those at 90'. As mentioned earlier, the current speeds at 120' were frequently below the minimum threshold capability of the rotor. It is probable that the vane response to movement is also close to its minimum range of detection. More observations at higher speeds are needed to determine if the currents normally shift in a clockwise movement with increasing depth. The speed ranges are shown on the histogram plotted. The polar coordinate diagrams and Table 1 indicate a predominance of currents from the northwest during the period sampled.

Significance of Findings

The data show that an effluent discharged into the lake, at any depth, can have a prevailing direction of movement. During the period of May to July 1961, this movement at the test station would normally have been from the northwest at the three levels observed.

The maximum consecutive readings from the northwest varied from three to more than four days with an average drift of 3 or more miles per day for the 60 and 90 foot levels. The rate of flow is expected to be higher in the upper layers.

Although mixing occurs during severe weather conditions the exact rate or amount is unknown. Earlier studies when the Chicago River was diverted into the lake in September 1960, shows that the discharged waters maintained a detectable coliform count for five days (13). Therefore, it may be possible that even during periods of high velocities for eight or more hours the effluent will not be mixed into the surrounding water.

The worst condition appears to be when an effluent would remain in the general vicinity of its discharge point because of extremely low velocities. After a period of build-up, the concentrated effluent might then be moved, en masse, by the current. Relatively slow currents could move the effluent for four or more days in one direction, as shown in Table 1, or a fast moving current could produce the same result within five to eight hours.

Relation to Previous Work

Little or no relationships can be made to previous work. The present study, although made from test data, far exceeds the current data collected from all other studies on Lake Michigan.

Ayers, et al. demonstrated the variations in the subsurface layers for specific time periods (3). Surface current studies using drift bottles and cards, which average over a period of time, may be better explained by the test data.

Frequently, the drift bottle or card flow will show quite variable conditions when obtained after being adrift for one or two days. Long term drift periods, weeks or more, many times show a type of "uniform" movement. The polar diagrams showed that the currents at a given station can be in any direction; however, there may be a prevailing dominance from a particular quadrant over a long period of time.

Present work indicates a far greater variability of flow than has been previously demonstrated. Johnson's work on Lake Michigan gave some indication of the variability from his transects (2). The current speed ranges from near zero to more than 1.3 fps. The ranges observed are certainly not the maximum values that can be expected.

SUMMARY

The data and performance tests from the first meters set in Lake Michigan have been examined and evaluated. The tests were made to evaluate the type of meters to be used and reliability of the instruments' internal components. The test data were examined for persistency of movement and the variations of speed with depth.

A literature search disclosed three intensive studies. These investigations, using drift bottles or drift cards and dynamic height methods, were limited in scope and disclosed the random variations found in the surface layers. Only Harrington in the 1895 studies attempted to show that a prevailing pattern existed.

Three types of meter systems were evaluated and the Woods Hole meter was selected because of the established performance record of its internal components, type of data collected and lower cost.

The test data were examined to determine the reliability and sensitivity of meters for measuring both speed and direction. The data from the instruments using one type of mooring system indicated that the large surface float had an effect on the vane direction. The mooring system was altered to eliminate this possible source of error.

The study did not show a positive correlation between the estimated wind and the currents at the 60 foot level. However, detection may be difficult using shore based wind data and currents at the 60 foot depth.

The median values for speed and direction were examined for random fluctuations and the 95% confidence limits indicate the instruments had a sufficient degree of precision. Currents at the 90 foot level were somewhat slower and to the right of those at the 60 foot level. Although the vane directions at 120' were not to the right of those at 90', as mentioned earlier, the general direction of flow was nearly the same for both depths. Normally the speeds were greater at 60' as compared to those at 90' or 120'. However, on occasions the speeds were highest at the 90' depth. These variations are possibly due to changes of the thermocline which could produce the observed departures from this rule.

Polar diagrams for a two month period show a predominant flow from the northwest quadrant for all depths. The maximum consecutive

readings in each quadrant show that movement from the northwest can persist for more than four days, whereas the maximum consecutive readings from the other three quadrants did not exceed one and one-half days.

The data tabulated for May to July 1962, show that under certain conditions an effluent could move, at low speed with relatively little mixing, for over four days. Movement during other periods of the year may show that there are other quadrants in which the current will predominate for longer periods of time.

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Table I

Readings in Each Quadrant*

Meter 1 - 60' Deep

Quadrant	Maximum Consecutive Readings in Quadrant	Observation Number	Observation Per Cent of Time	Average** Magnitude fps	Average** Direction deg.
0-90°	4	62	24.3	.185	42
90-180°	3	33	12.9	.191	139
180-270°	3	58	22.8	.216	228
270-360°	20	102	40.0	.222	310
			100.0		

Meter 2 - 90' Deep

0-90°	4	77	25.6	.173	43
90-180°	9	59	19.7	.144	131
180-270°	5	60	20.0	.182	228
270-360°	26	104	34.7	.251	316
			100.0		

Meter 3 - 120' Deep

0-90°	3	66	22.0	.018	38
90-180°	6	63	21.0	.004	138
180-270°	3	73	24.3	.005	223
270-360°	13	98	32.7	.011	314
			100.0		

*Readings are approximately four hours apart.
**Arithmetic average of magnitude and direction.

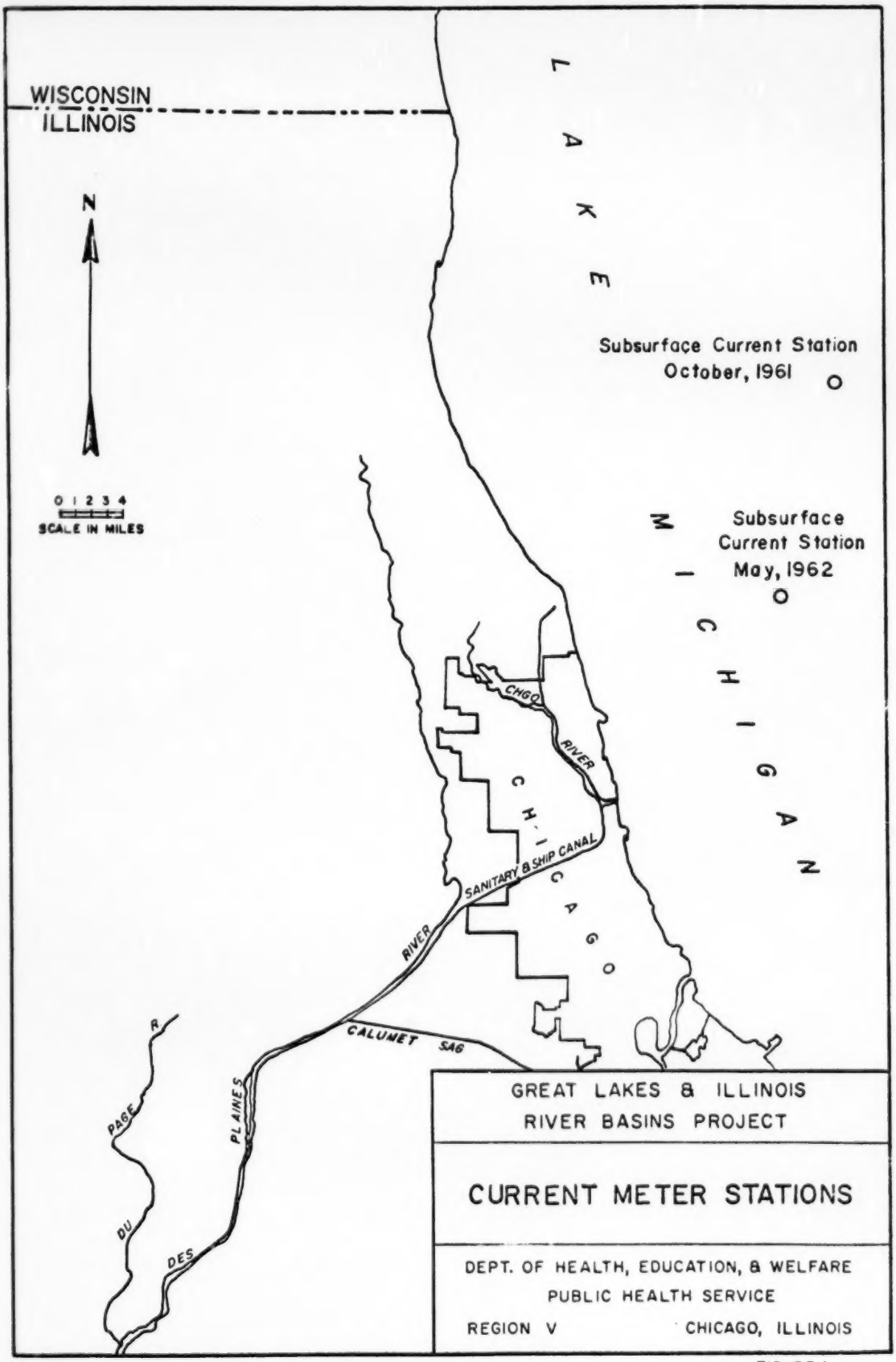
WISCONSIN
ILLINOIS
LAKE
MICHIGAN
N
0 1 2 3 4
SCALE IN MILES
Subsurface Current Station
October, 1961
Subsurface
Current Station
May, 1962
CHGO. RIVER
CHICAGO
SANITARY & SHIP CANAL
CALUMET SAG
RIVER
PAGE
DU
PLAINES
DES
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
CURRENT METER STATIONS
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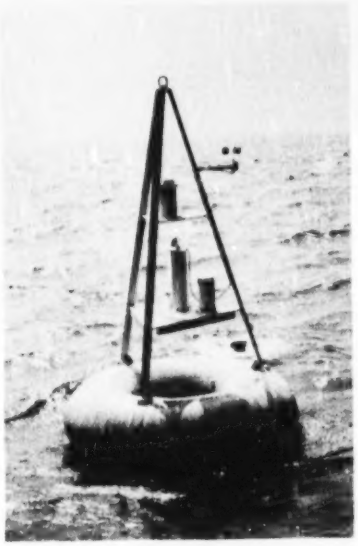
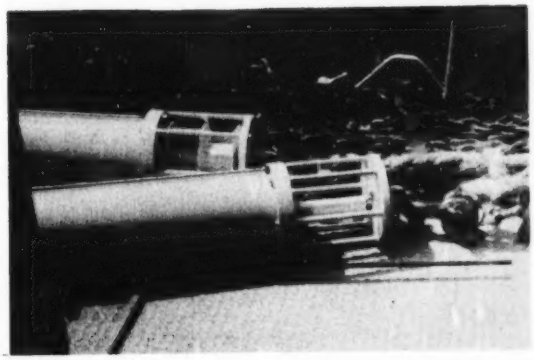
FIGURE 1



Surface Buoy Containing
Anemometer and Light



Background - Rotor of Current Meter
Foreground - Vane of Current Meter

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

WOODS HOLE METER

DEPT. OF HEALTH, EDUCATION, & WELFARE
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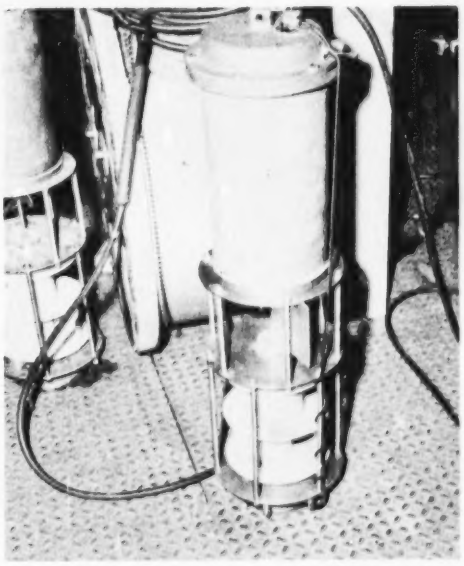
FIGURE 2

Instrument Buoy - Approximate Height 9 Feet



Savonius Meter With Direction Vane and Digitizer

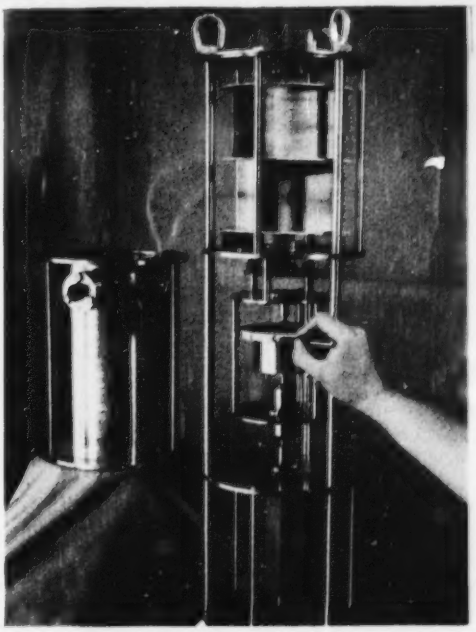
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

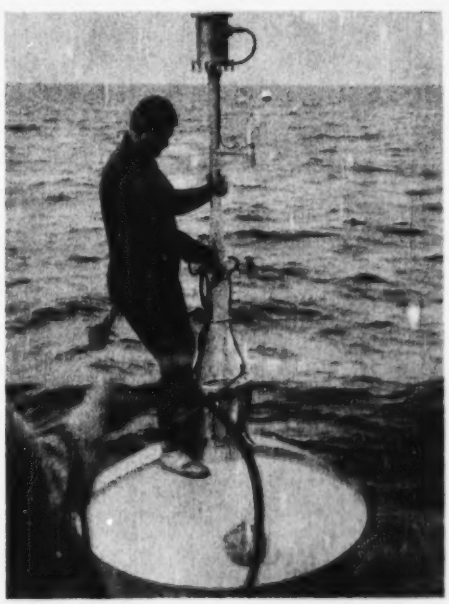
TELEMETRY METER

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 3

Current and Temperature Sensor





Surface Buoy Containing Anemometer and Navigation Light.

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

INTEGRATED CURRENT METER

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

GPO 827804

FIGURE 4

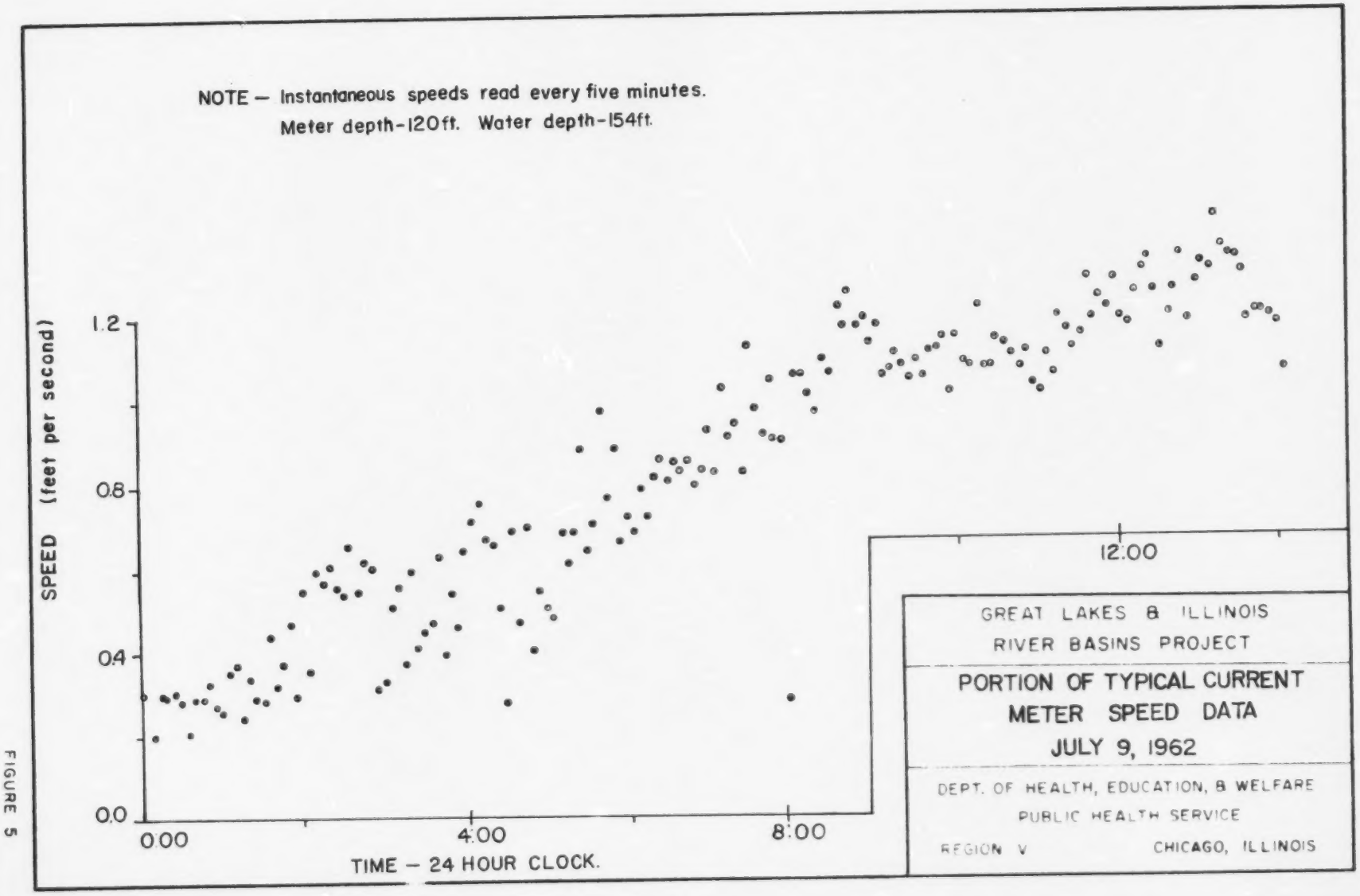

NOTE — Instantaneous speeds read every five minutes.
Meter depth-120ft. Water depth-154ft.
SPEED (feet per second)
1.2
0.8
0.4
0.0
0.00
4.00
8.00
12.00
TIME — 24 HOUR CLOCK.
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
PORTION OF TYPICAL CURRENT
METER SPEED DATA
JULY 9, 1962
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 5

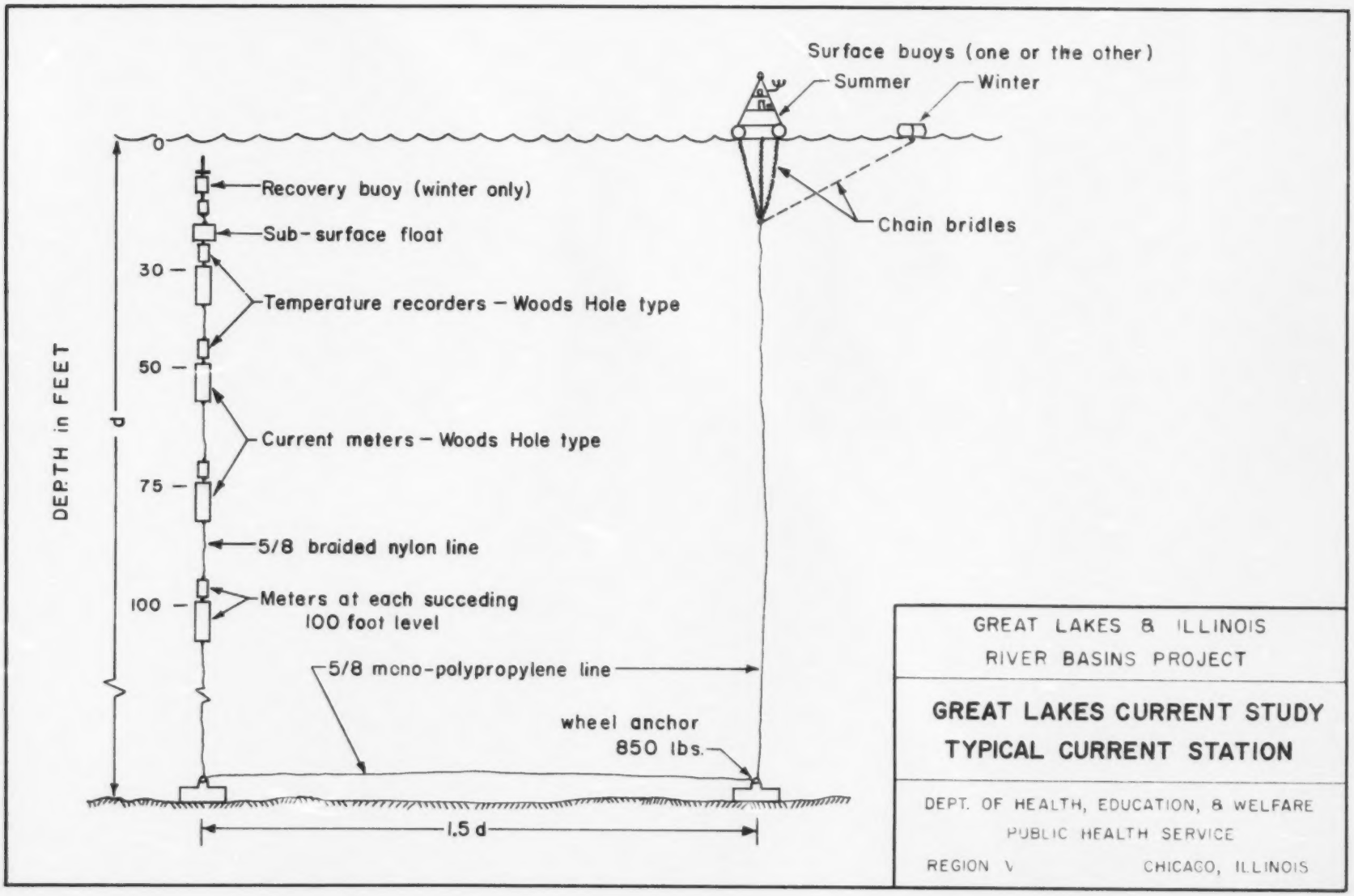
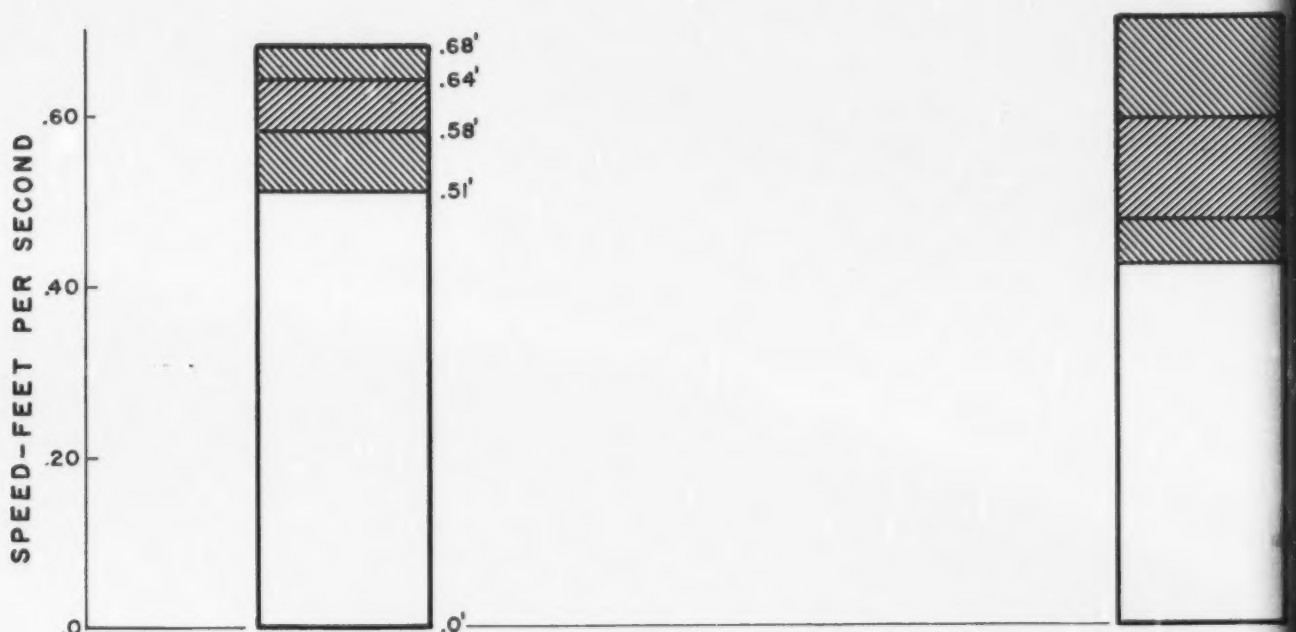
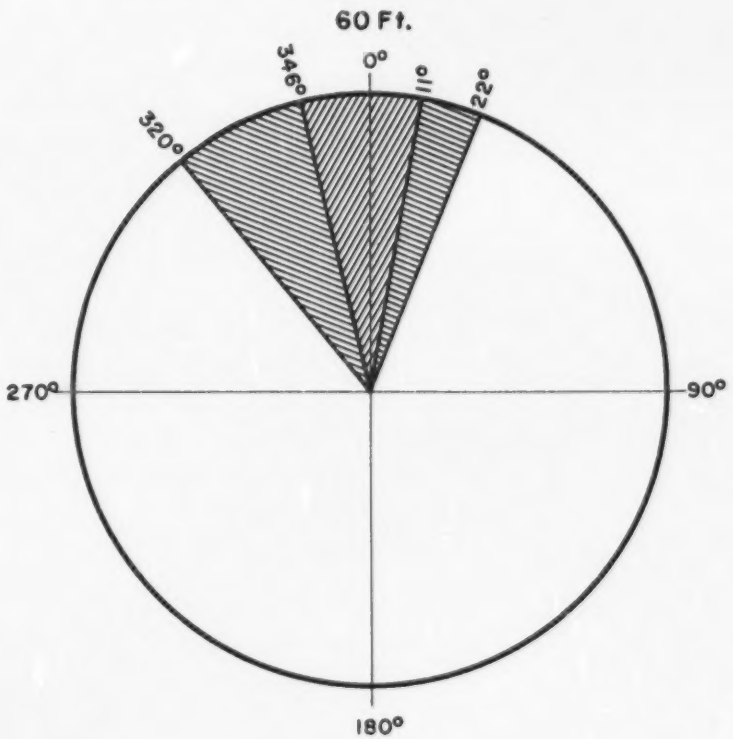
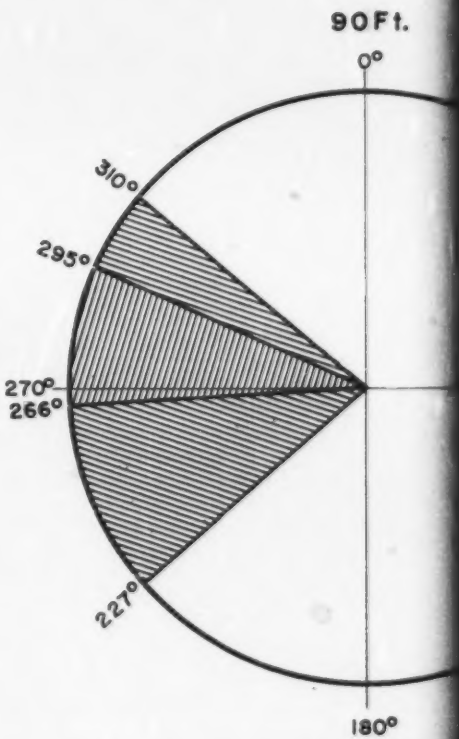

Surface buoys (one or the other)
Summer
Winter
0
Recovery buoy (winter only)
Sub-surface float
30
Temperature recorders – Woods Hole type
50
Current meters – Woods Hole type
75
5/8 braided nylon line
100
Meters at each succeding 100 foot level
5/8 mono-polypropylene line
wheel anchor 850 lbs.
Chain bridles
DEPTH in FEET
d
1.5 d
GREAT LAKES & ILLINOIS RIVER BASINS PROJECT
GREAT LAKES CURRENT STUDY
TYPICAL CURRENT STATION
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 6

M A G N I T

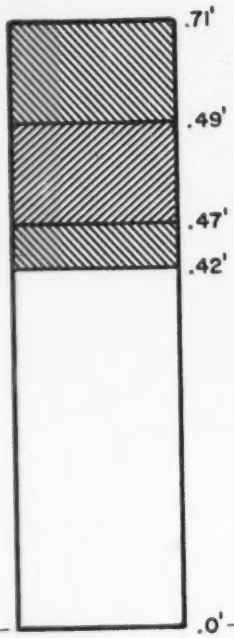


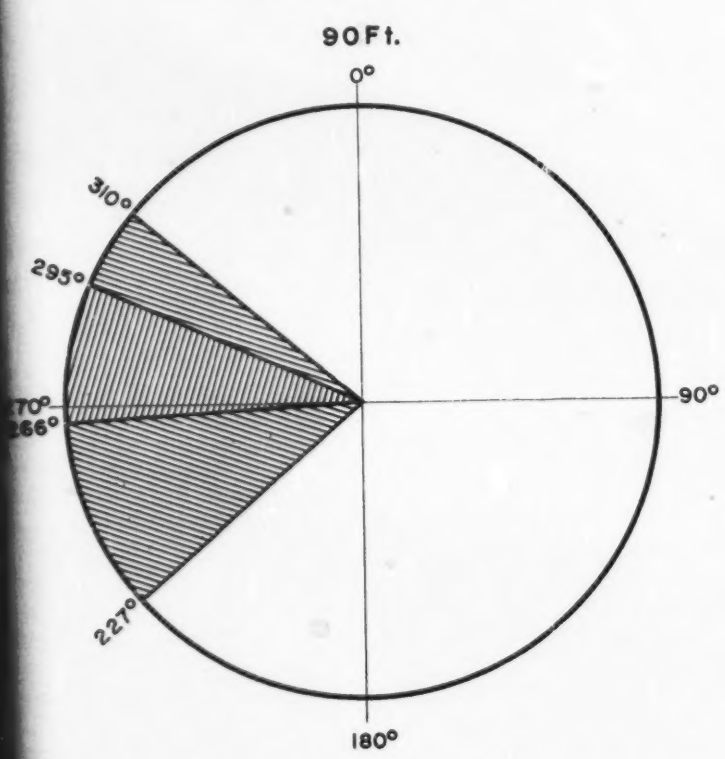


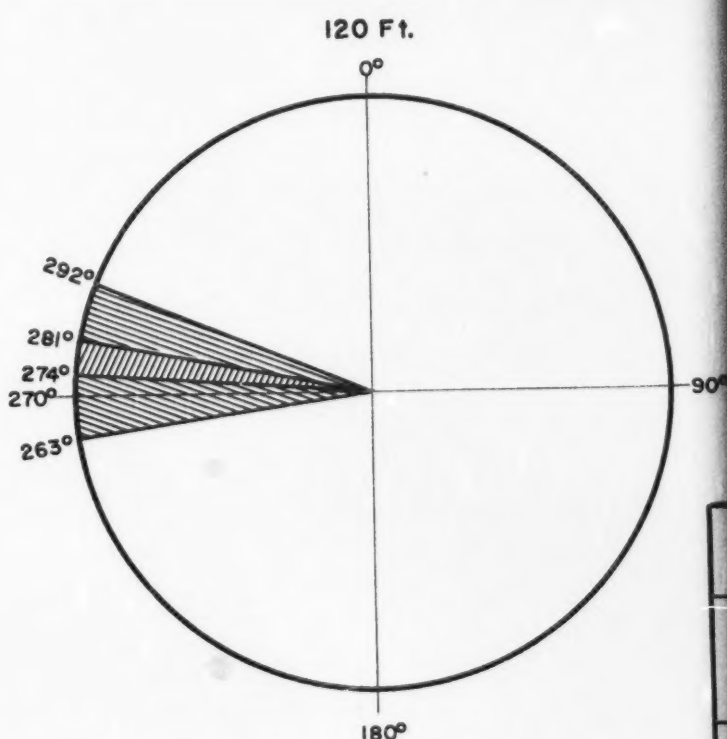


D I R E C T

M A G N I T U D E



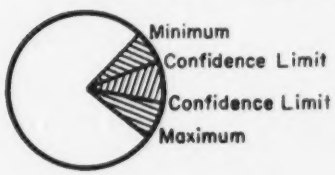




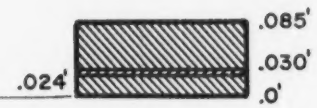
D I R E C T I O N

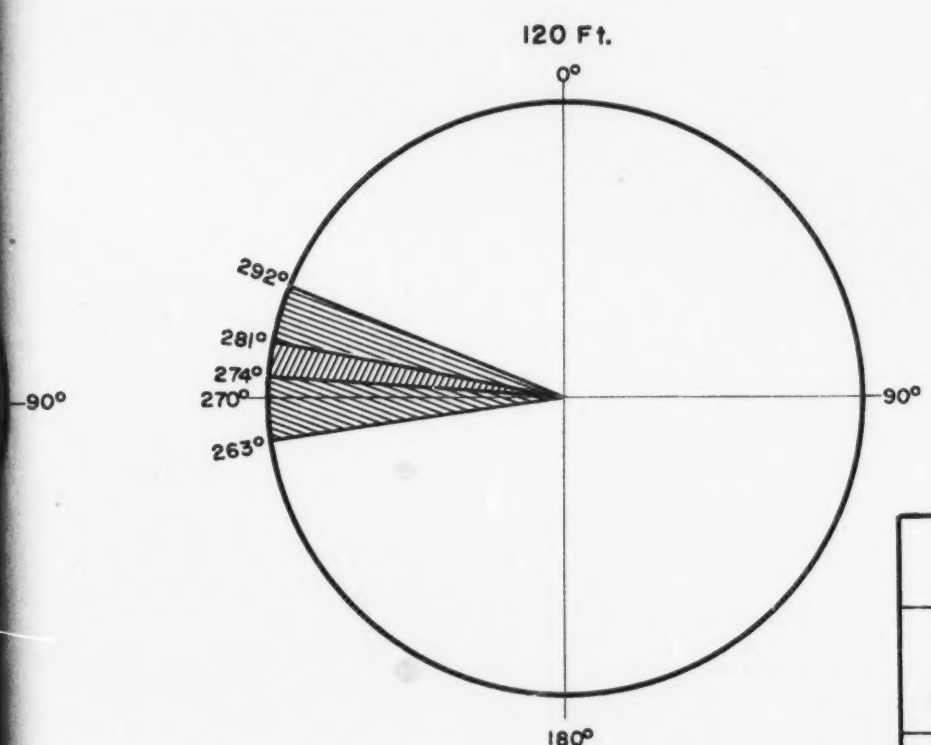
LEGEND

Water Depths-60', 90', & 120'



18 Readings – July 12, 1962, 12:10-16:04 hours



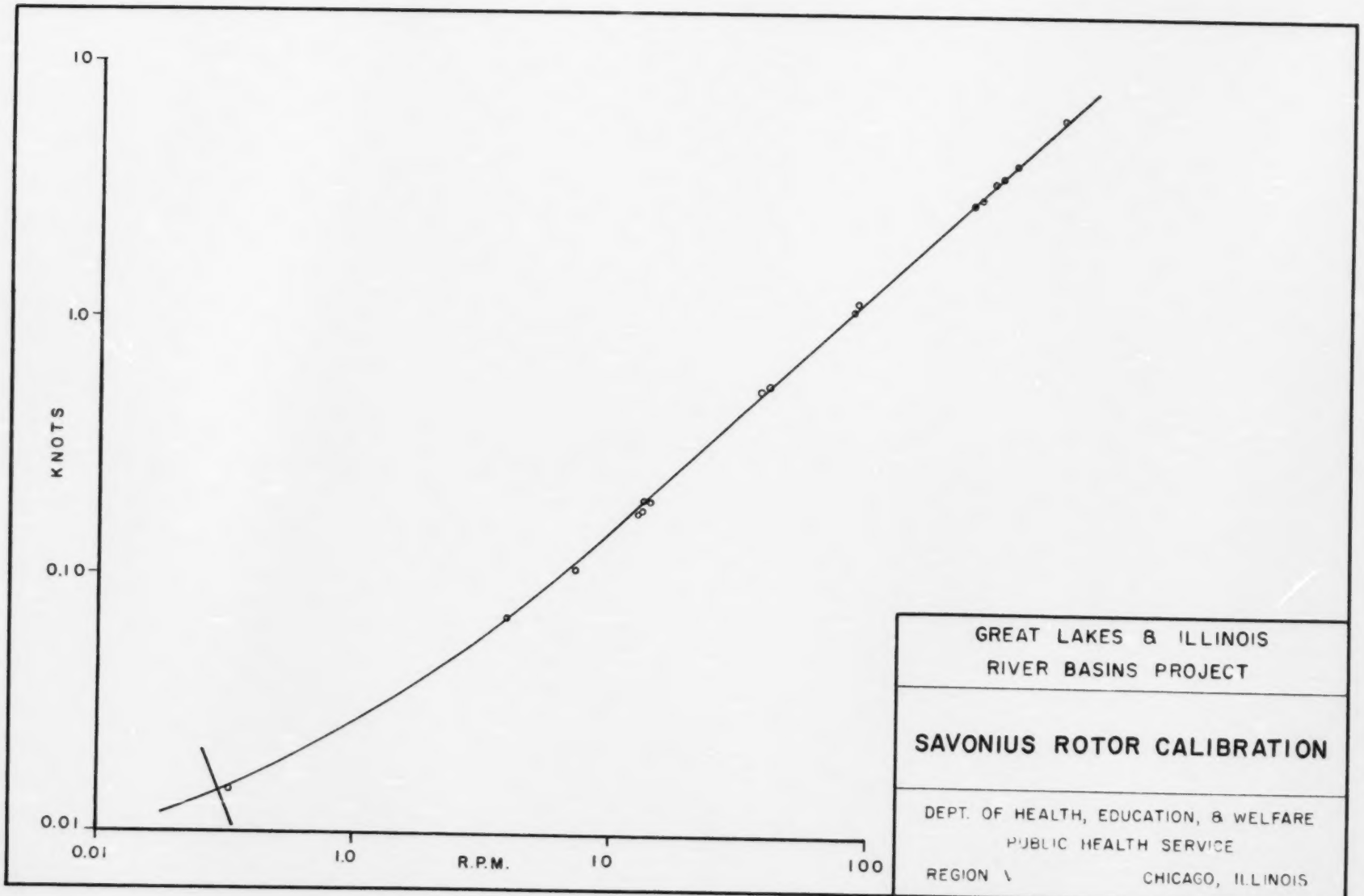


GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

95% CONFIDENCE LIMITS FOR MEDIAN SPEEDS & DIRECTIONS

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 7

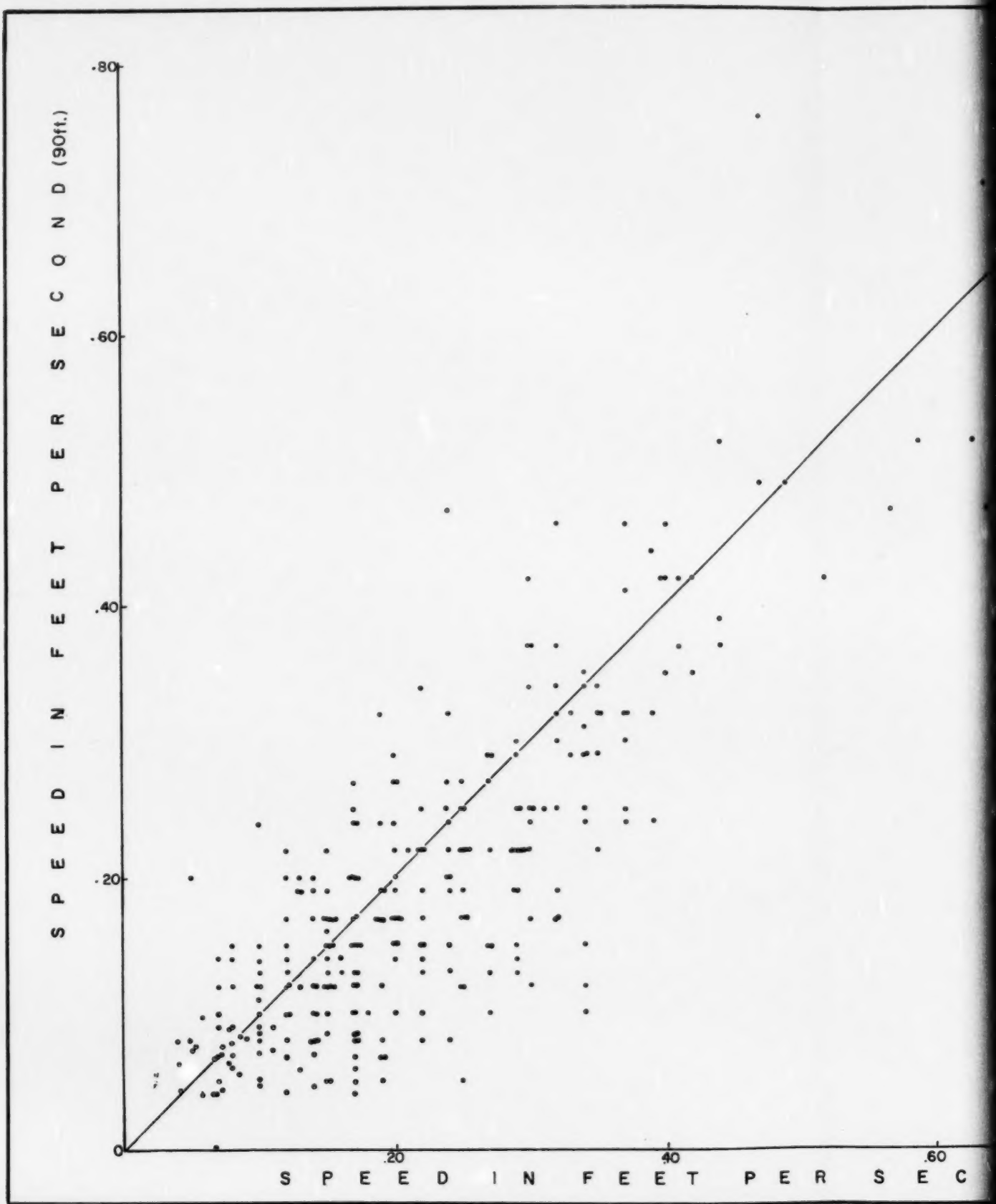


GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

SAVONIUS ROTOR CALIBRATION

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 8


SPEED IN FEET PER SECOND (90ft.)
.80
.60
.40
.20
0
.20
.40
.60
SPEED IN FEET PER SEC

LEGEND
Four hour
All availa
Period: May
.40
.60
.80
E T P E R S E C O N D (60 ft.)

LEGEND

Four hour averages.

All available data was used.

Period: May 26, 1962 – July 26, 1962.

.80

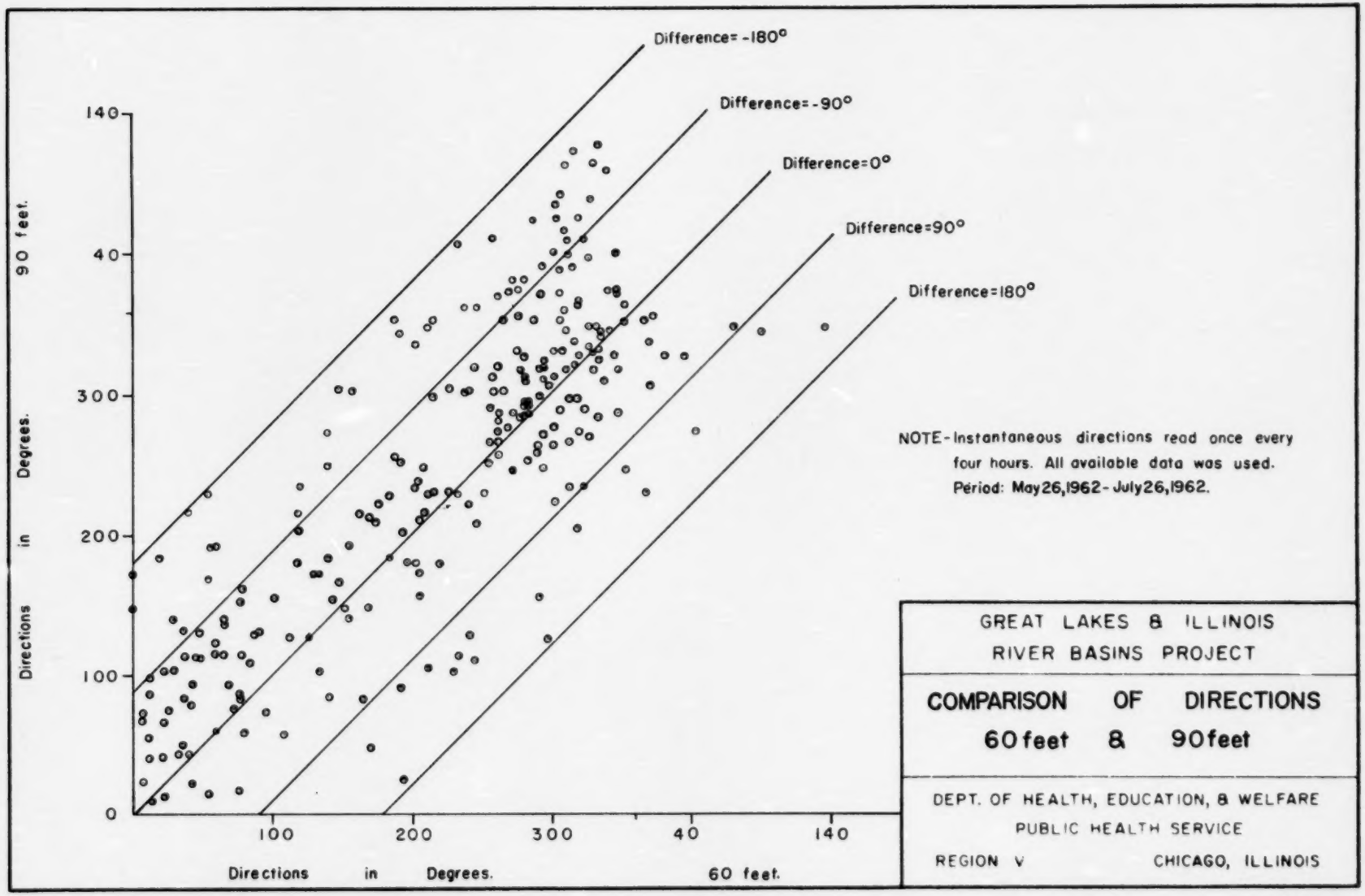
ft.)

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

COMPARISON OF SPEEDS AT 60 FEET AND 90 FEET

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 9



NOTE- Instantaneous directions read once every four hours. All available data was used. Period: May 26, 1962 - July 26, 1962.

GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

COMPARISON OF DIRECTIONS 60 feet & 90 feet

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

GPO 827804

FIGURE 10

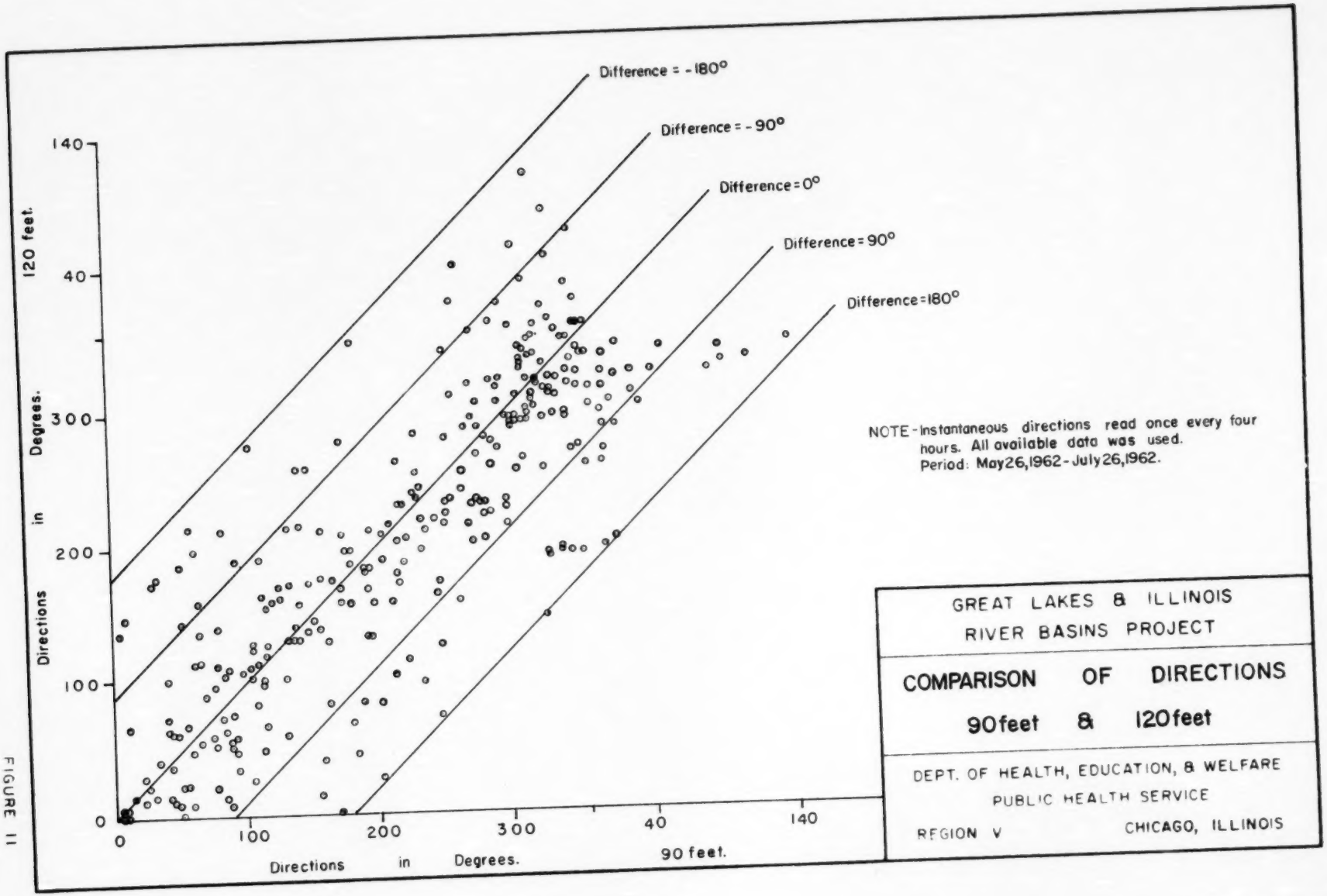
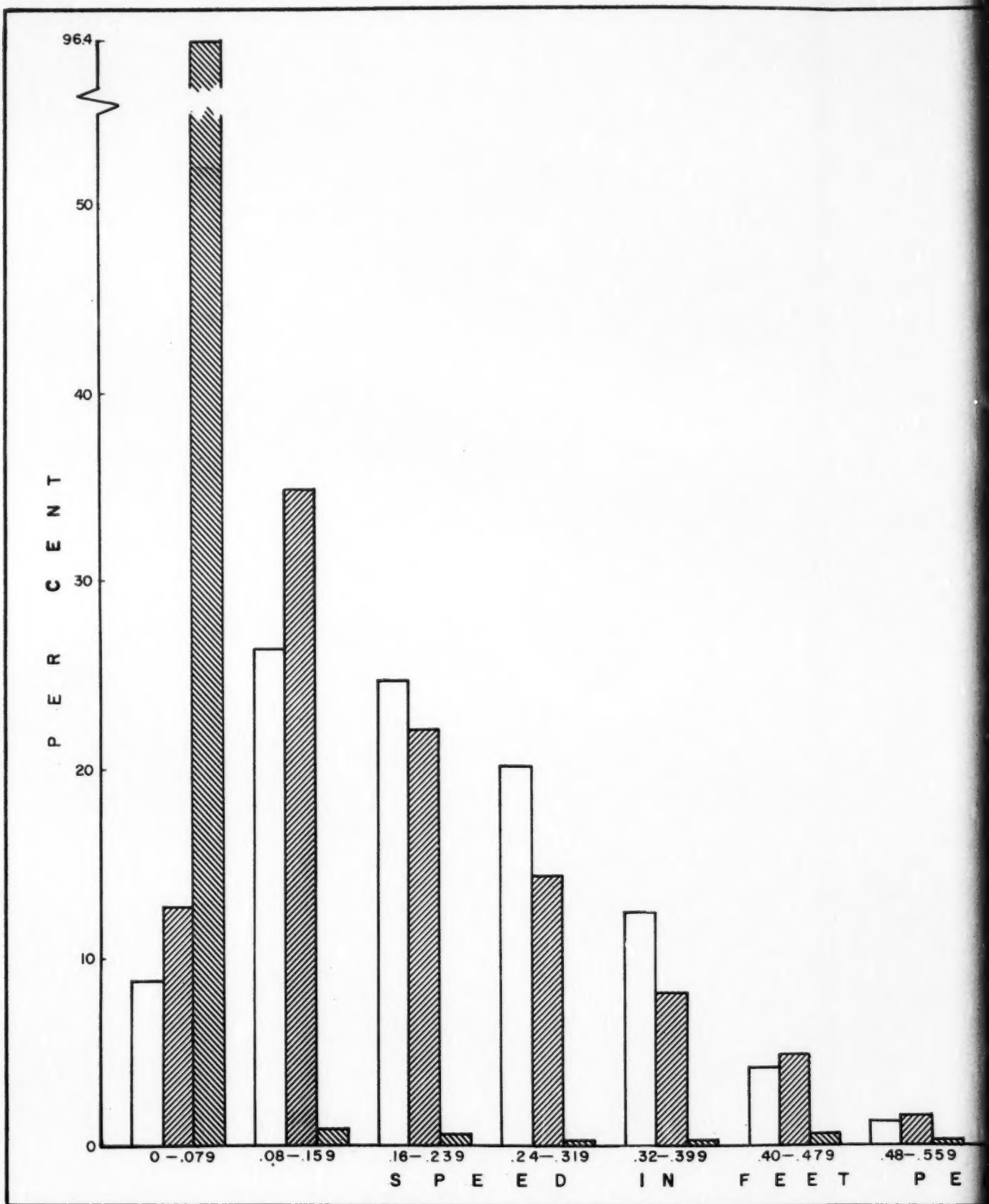

Difference = -180°
Difference = -90°
Difference = 0°
Difference = 90°
Difference = 180°
140
40
300
200
100
0
Directions in Degrees. 120 feet.
0
100
200
300
40
140
Directions in Degrees. 90 feet.
NOTE - Instantaneous directions read once every four hours. All available data was used.
Period: May 26, 1962 - July 26, 1962.
GREAT LAKES & ILLINOIS RIVER BASINS PROJECT
COMPARISON OF DIRECTIONS
90 feet & 120 feet
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 11


96.4
50
40
30
20
10
0
PER CENT
0 – .079
.08 – .159
.16 – .239
.24 – .319
.32 – .399
.40 – .479
.48 – .559
SPEED IN FEET PE

GPO 827804

LEGEND

Meter

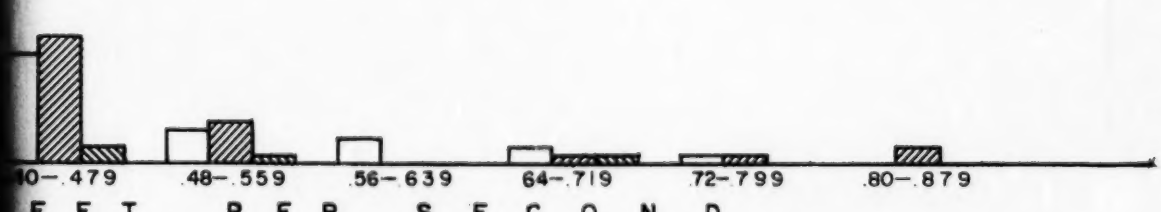
Meter

Meter

Perio

July 2

Four



G

H

DEPT.

REGIO

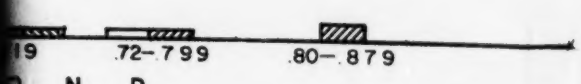
LEGEND

Meter 1-60 feet deep

Meter 2-90 feet deep

Meter 3-120 feet deep

Period: May 26, 1962–
July 26, 1962
Four Hour Averages

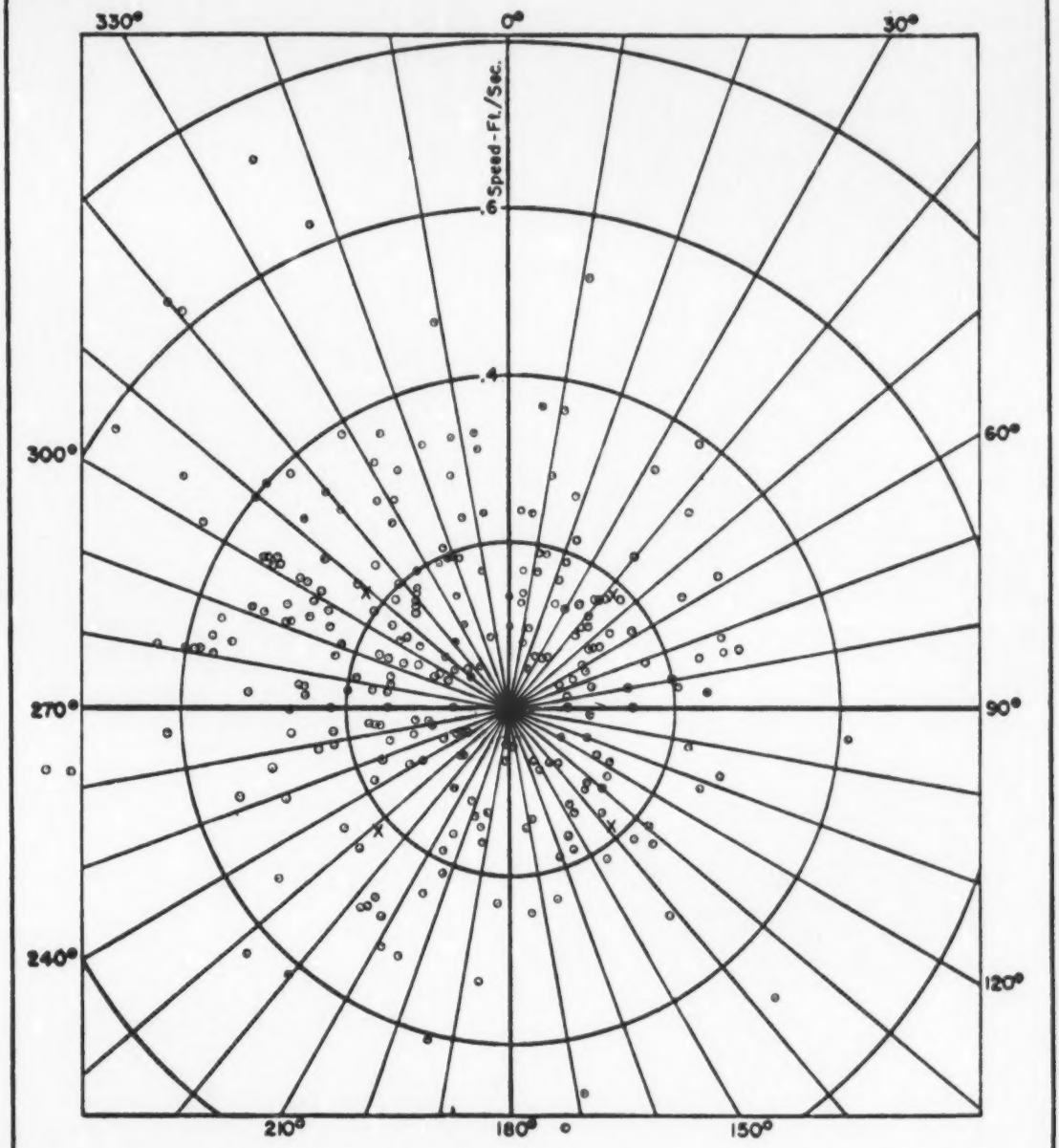


GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

HISTOGRAM OF SPEED AT THREE LEVELS

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 12



NOTE:

Speed averaged over four hours. Instantaneous direction measured at end of each period.

Period: May 26, 1962 - July 26, 1962

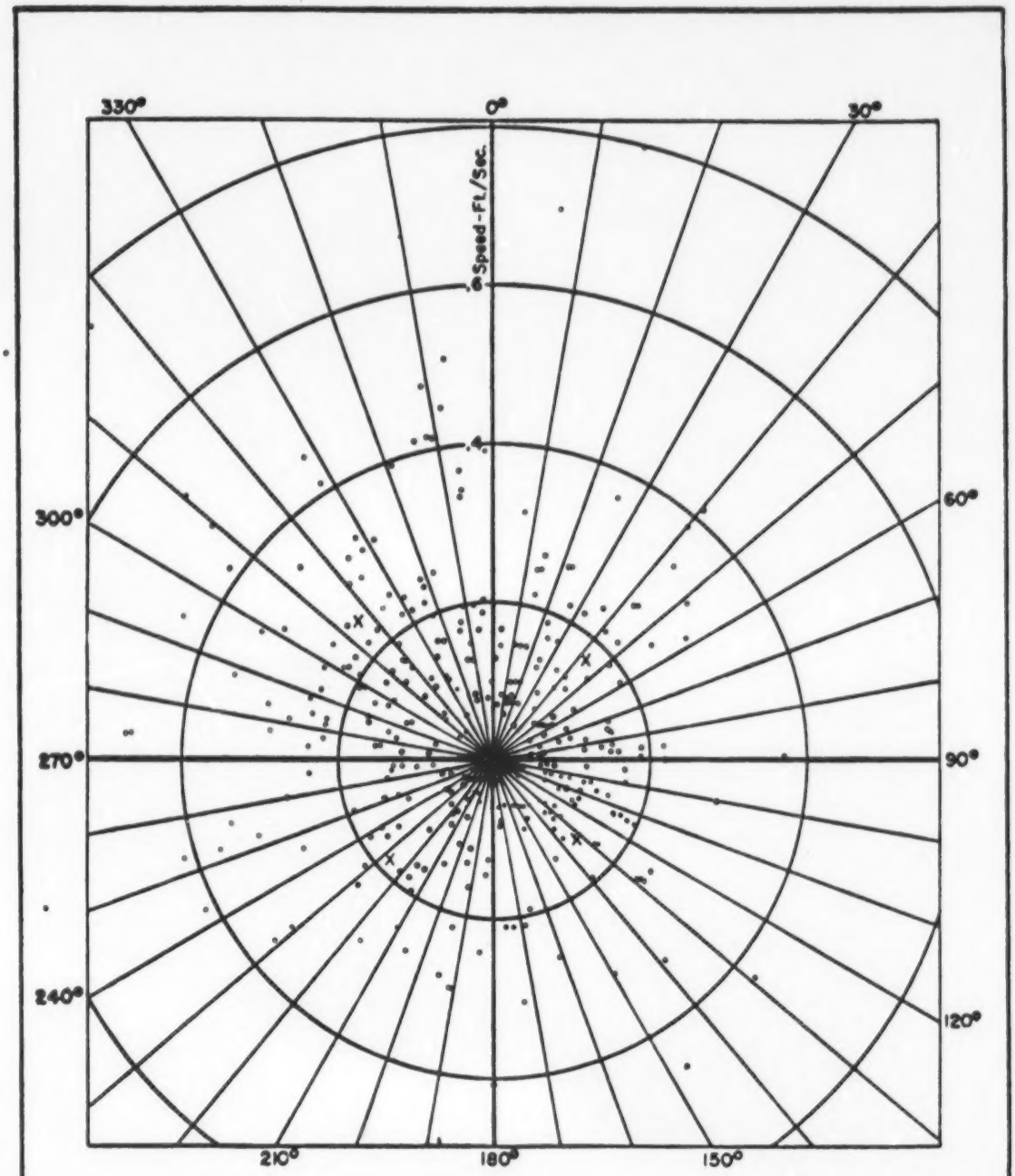
X Average velocity for quadrant (Table I)

GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

POLAR DIAGRAM OF MAGNITUDE AND DIRECTION AT 60 FT.

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 13



NOTE:

Speed averaged over four hours. Instantaneous direction measured at end of each period.

Period: May 26, 1962 - July 26, 1962.

The three points located outside the graph limits are: 310°, .82 f.p.s.; 288°, .76 f.p.s.; and 252°, .62 f.p.s.

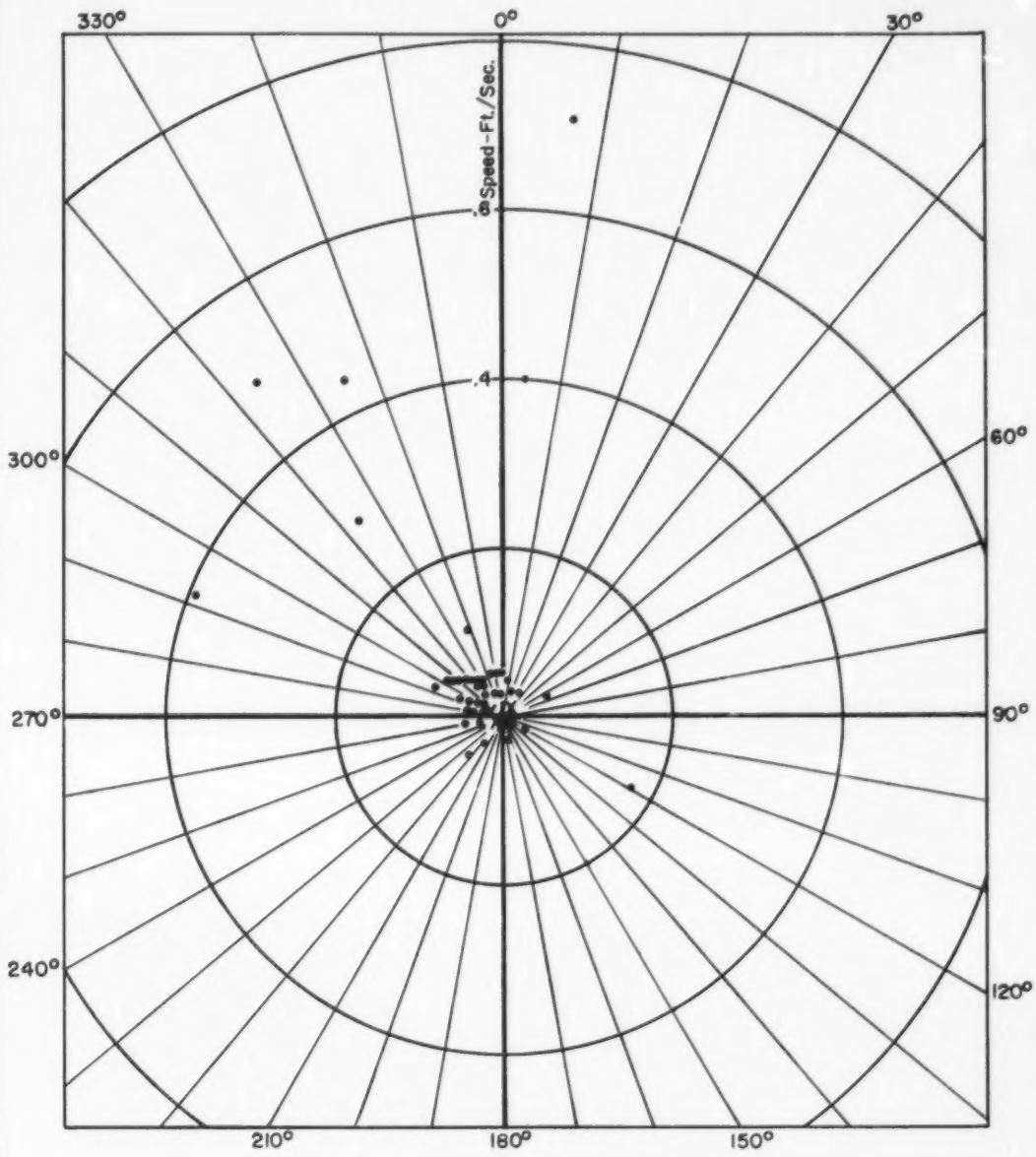
X Average velocity for quadrant (Table I)

GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

POLAR DIAGRAM OF MAGNITUDE AND DIRECTION AT 90 FT.

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 14



NOTE:
Speed averaged over four hours. Instantaneous direction measured at end of each period.
Period: May 26, 1962 - July 26, 1962

X Average velocity for quadrant (Table I)

GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

POLAR DIAGRAM OF MAGNITUDE AND DIRECTION AT 120 FT.

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

GPO 827804

FIGURE 15